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(56) Documents Cited
GB 1272990 A
WO 1997/001197 A1
US 4620155 A
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DE 004327917 A
US 3761933 A

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(54) Abstract Title
Loop antennae with opposed gaps

(57) An antenna comprises a single loop 10 having opposed gaps 12, 14. The antenna can be formed by etching copper on a PCB. In another embodiment (Fig. 6), two such loops are arranged orthogonally and by switching across one of the gaps (Fig. 10) the antenna can be operated selectively in horizontal linear polarisation or in circular polarisation.

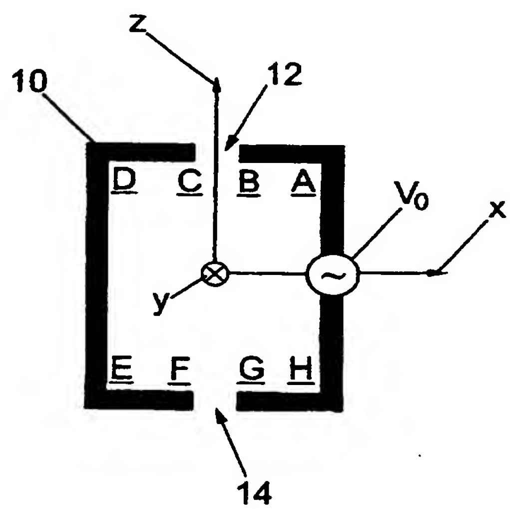

Fig. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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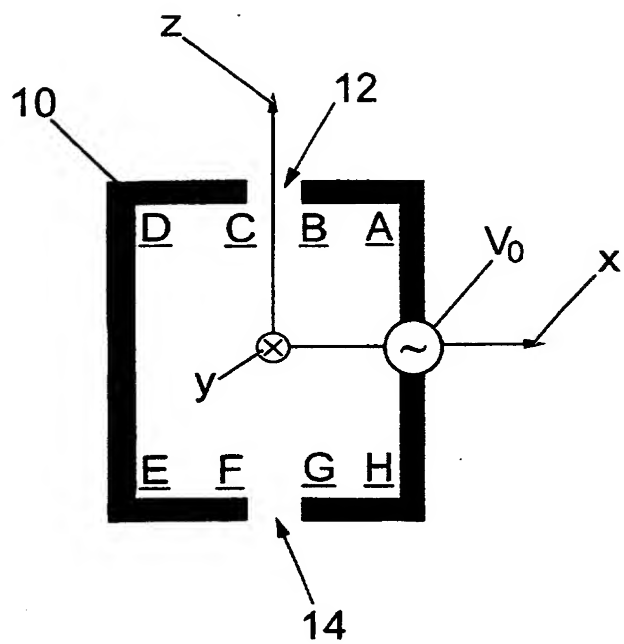


Fig. 1

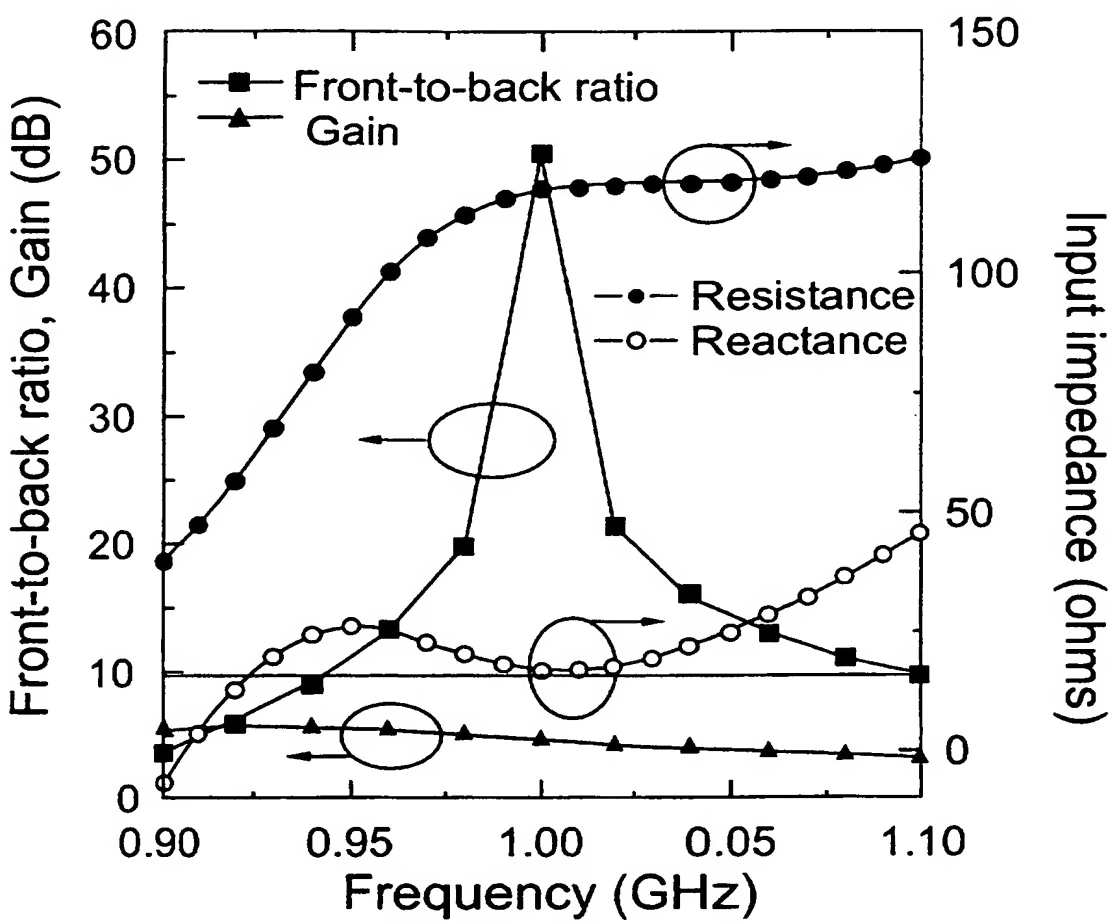

Front-to-back ratio
Gain
Resistance
Reactance
60
50
40
30
20
10
0
150
100
50
0
0.90
0.95
1.00
0.05
1.10
Frequency (GHz)
Front-to-back ratio, Gain (dB)
Input impedance (ohms)

Fig. 2

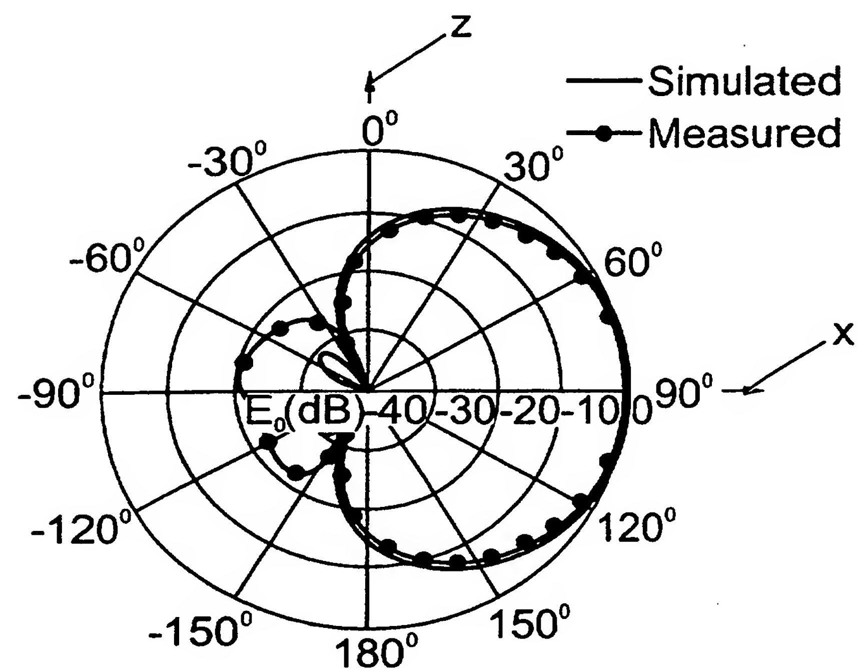

z
Simulated
Measured
0°
-30°
30°
-60°
60°
x
-90°
90°
E_0(dB)-40-30-20-10 0
-120°
120°
-150°
150°
180°

Fig. 3a

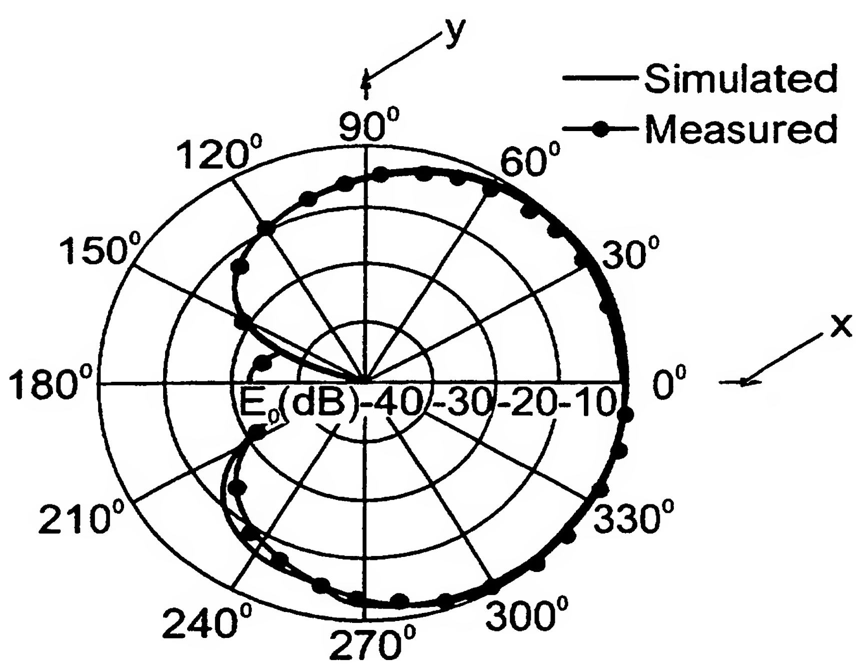

y
Simulated
Measured
90°
120°
60°
150°
30°
x
180°
0°
E_0(dB)-40-30-20-10
210°
330°
240°
300°
270°

Fig. 3b

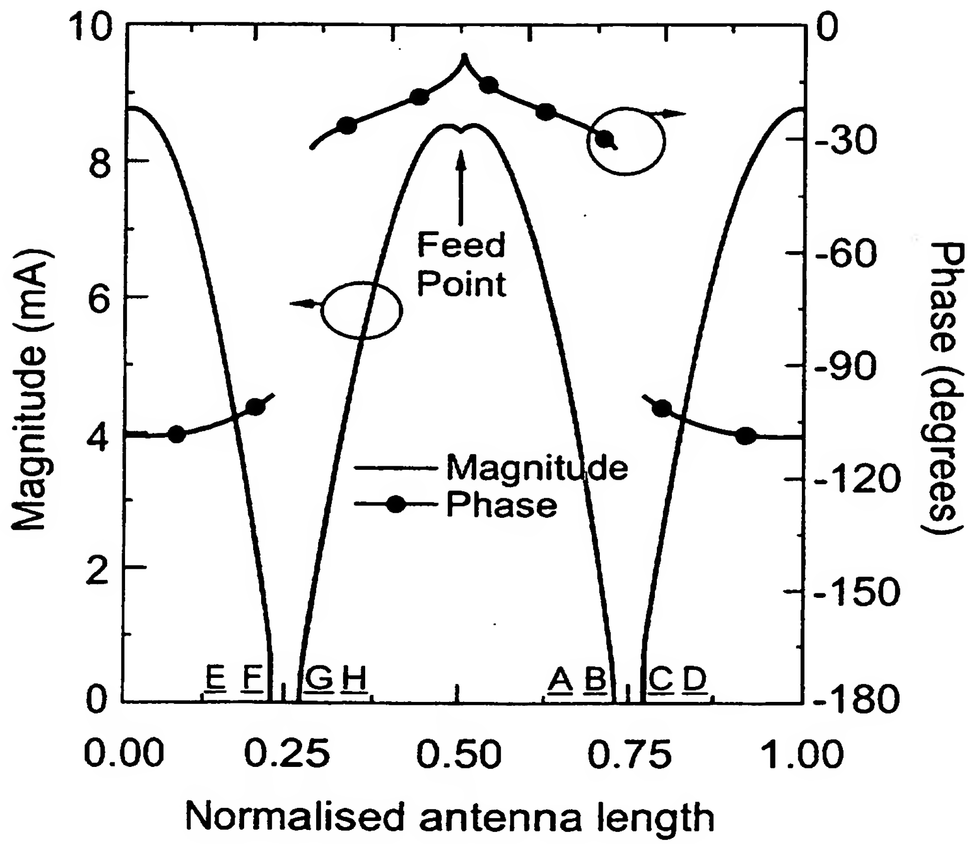

10
8
6
4
2
0
0
-30
-60
-90
-120
-150
-180
Magnitude (mA)
Phase (degrees)
Feed Point
Magnitude
Phase
E F G H A B C D
0.00
0.25
0.50
0.75
1.00
Normalised antenna length

Fig. 4

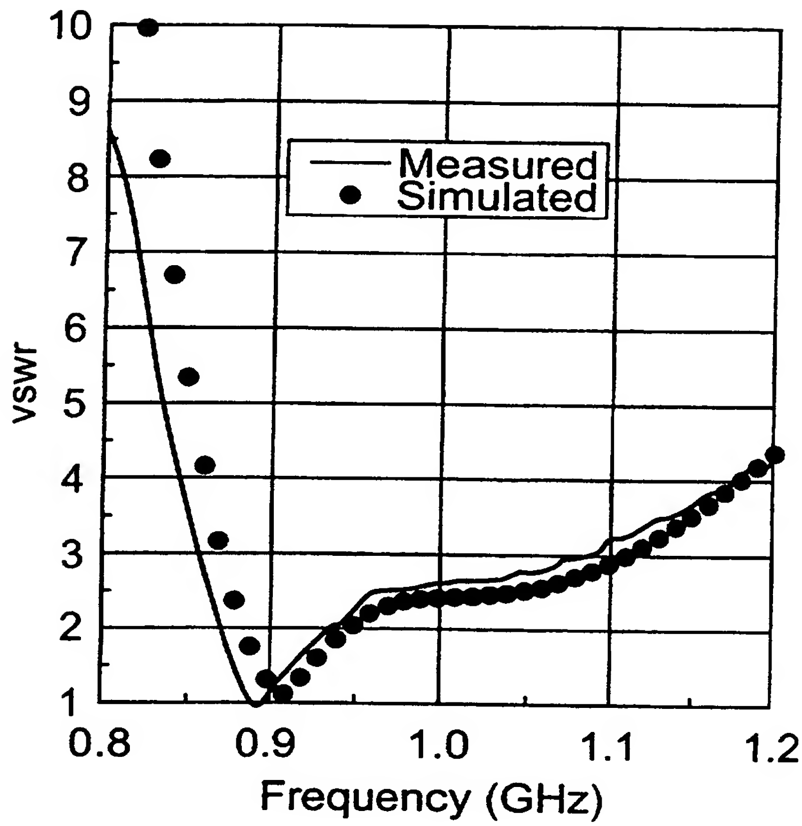

10
9
8
7
6
5
4
3
2
1
vswr
0.8
0.9
1.0
1.1
1.2
Frequency (GHz)
Measured
Simulated

Fig. 5

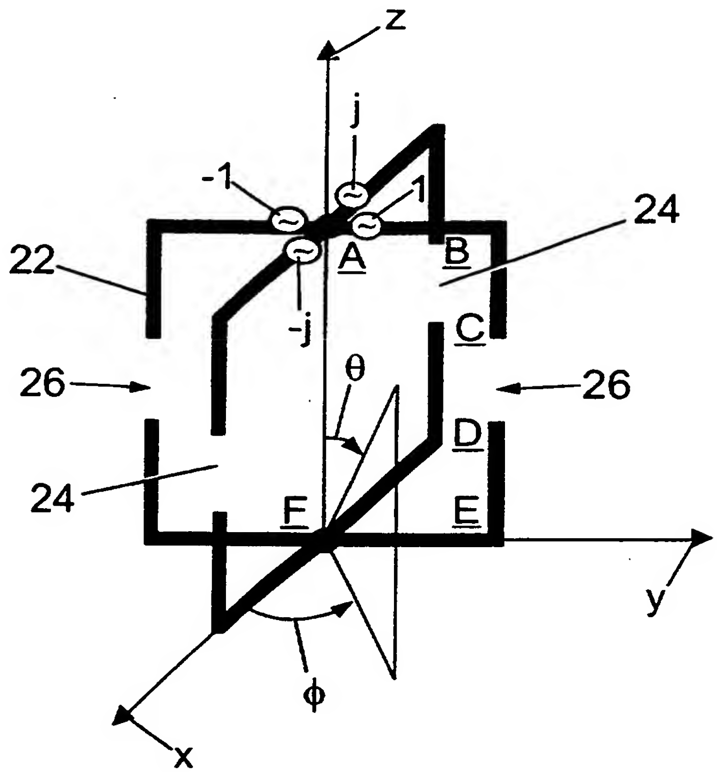
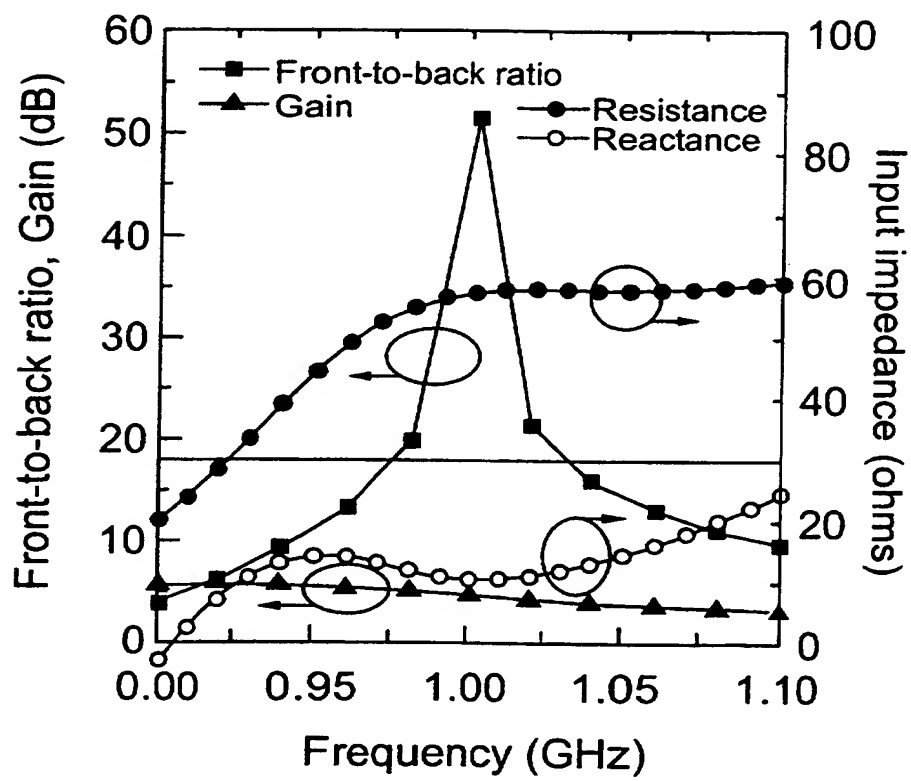


Fig. 6



60
50
40
30
20
10
0
100
80
60
40
20
0
Front-to-back ratio
Gain
Resistance
Reactance
Front-to-back ratio, Gain (dB)
Input impedance (ohms)
0.00
0.95
1.00
1.05
1.10
Frequency (GHz)

Fig. 7

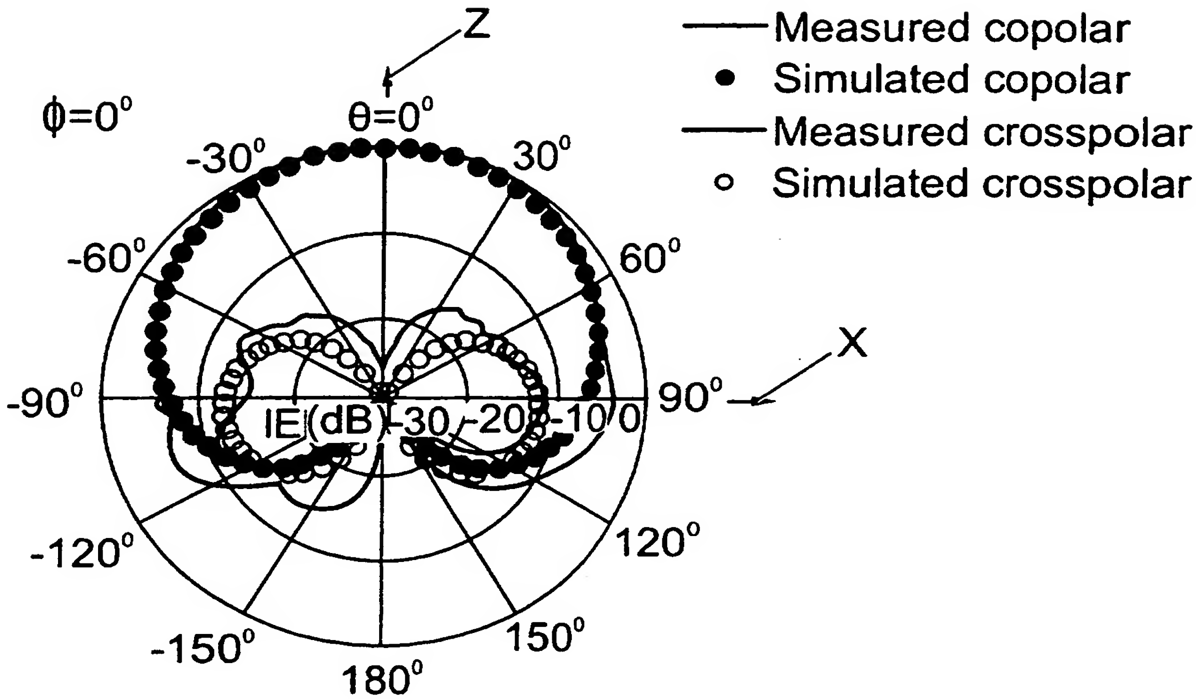


Fig. 8a ϕ=0°

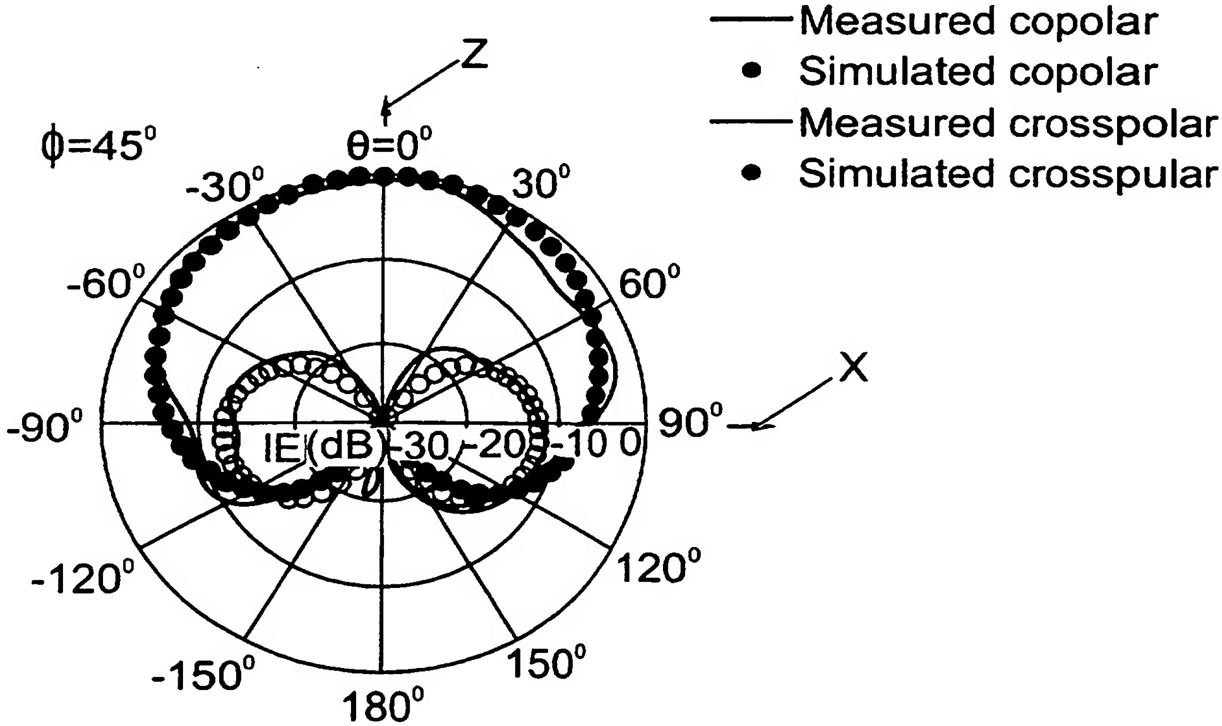
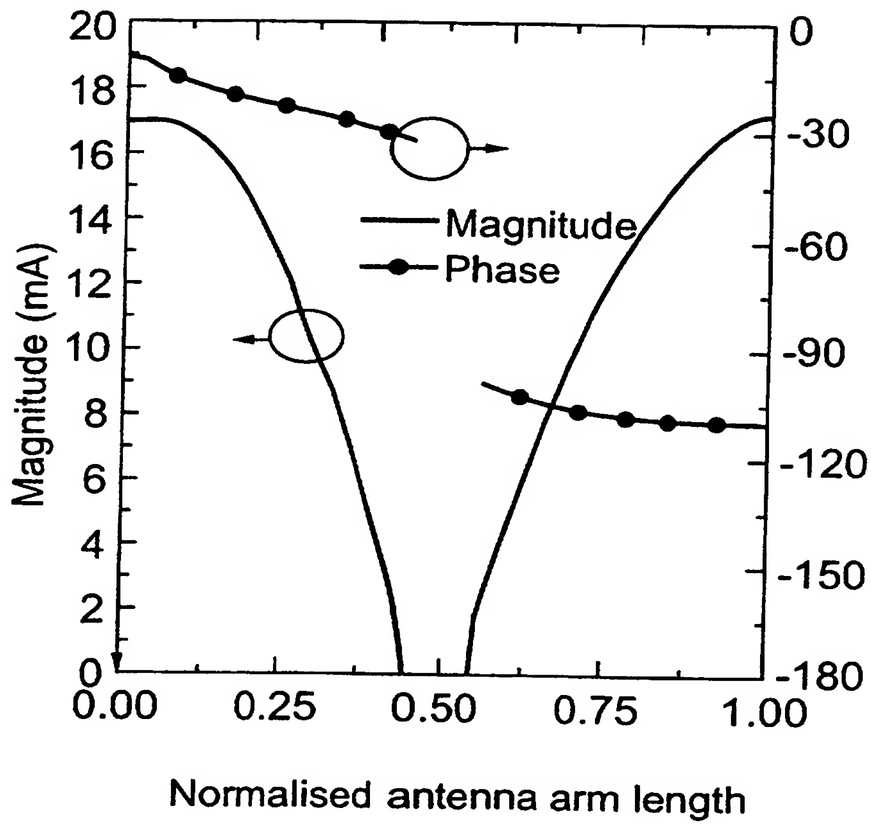


Fig. 8b ϕ=45°



Magnitude
Phase
Magnitude (mA)
Phase (degrees)
Normalised antenna arm length
20
18
16
14
12
10
8
6
4
2
0
0
-30
-60
-90
-120
-150
-180
0.00
0.25
0.50
0.75
1.00

Fig. 9

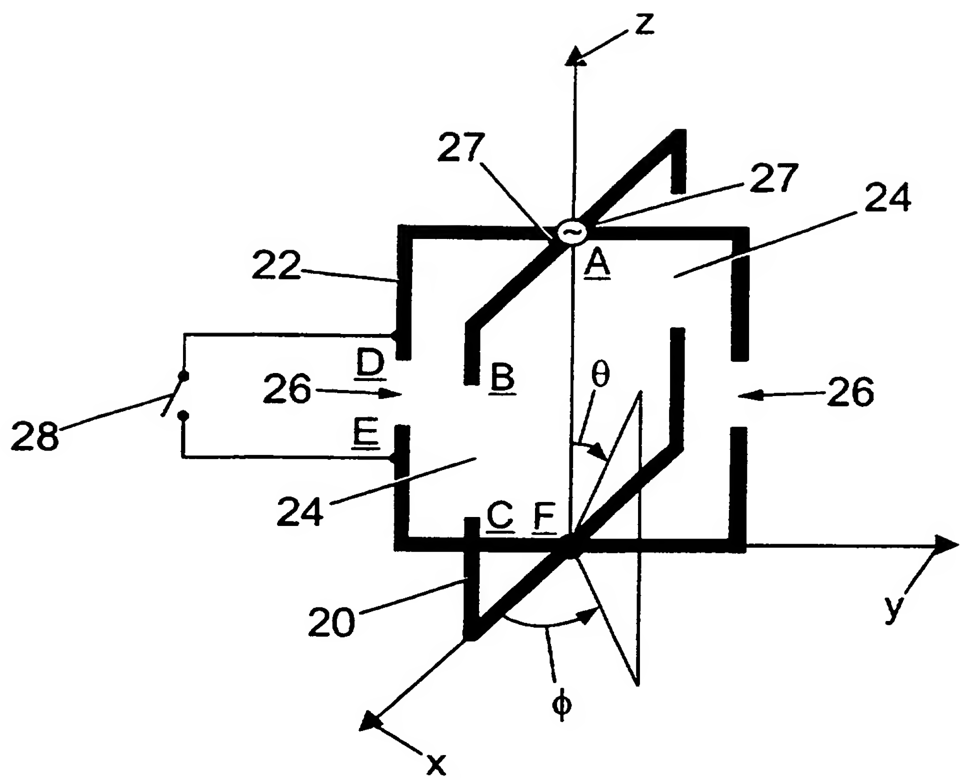
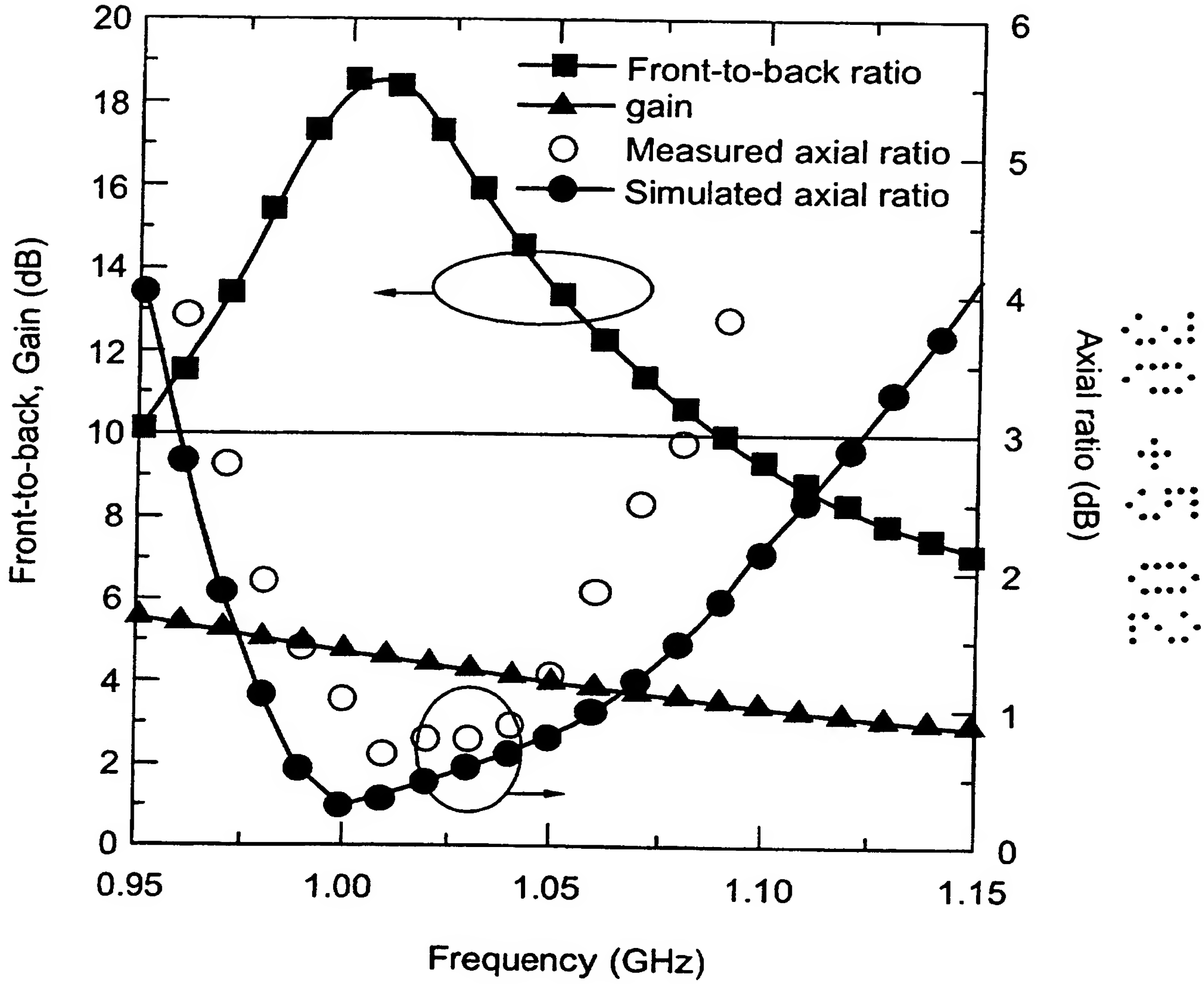


Fig. 10



Front-to-back ratio
gain
Measured axial ratio
Simulated axial ratio
Front-to-back, Gain (dB)
Axial ratio (dB)
Frequency (GHz)
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
0.95
1.00
1.05
1.10
1.15

Fig. 11

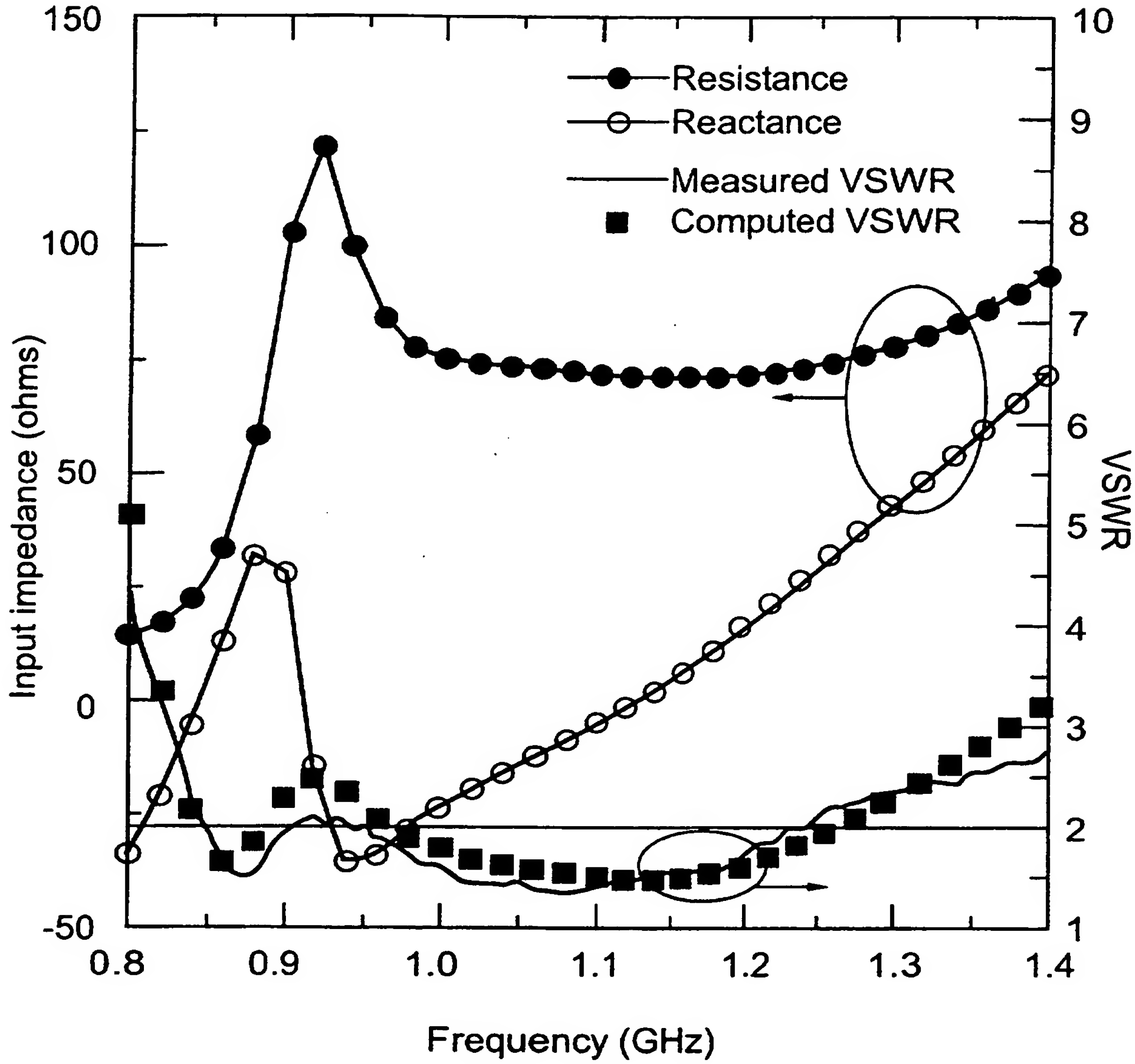

Resistance
Reactance
Measured VSWR
Computed VSWR
Input impedance (ohms)
VSWR
Frequency (GHz)
150
100
50
0
-50
10
9
8
7
6
5
4
3
2
1
0.8
0.9
1.0
1.1
1.2
1.3
1.4

Fig. 12

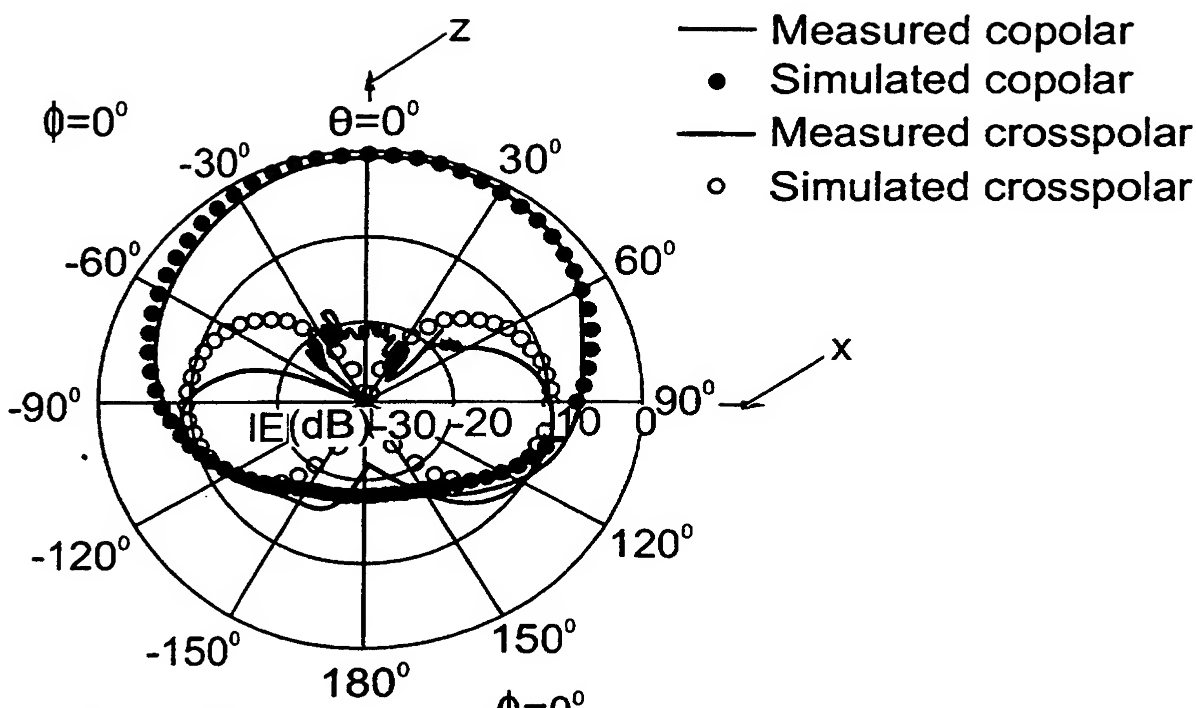


Fig. 13a

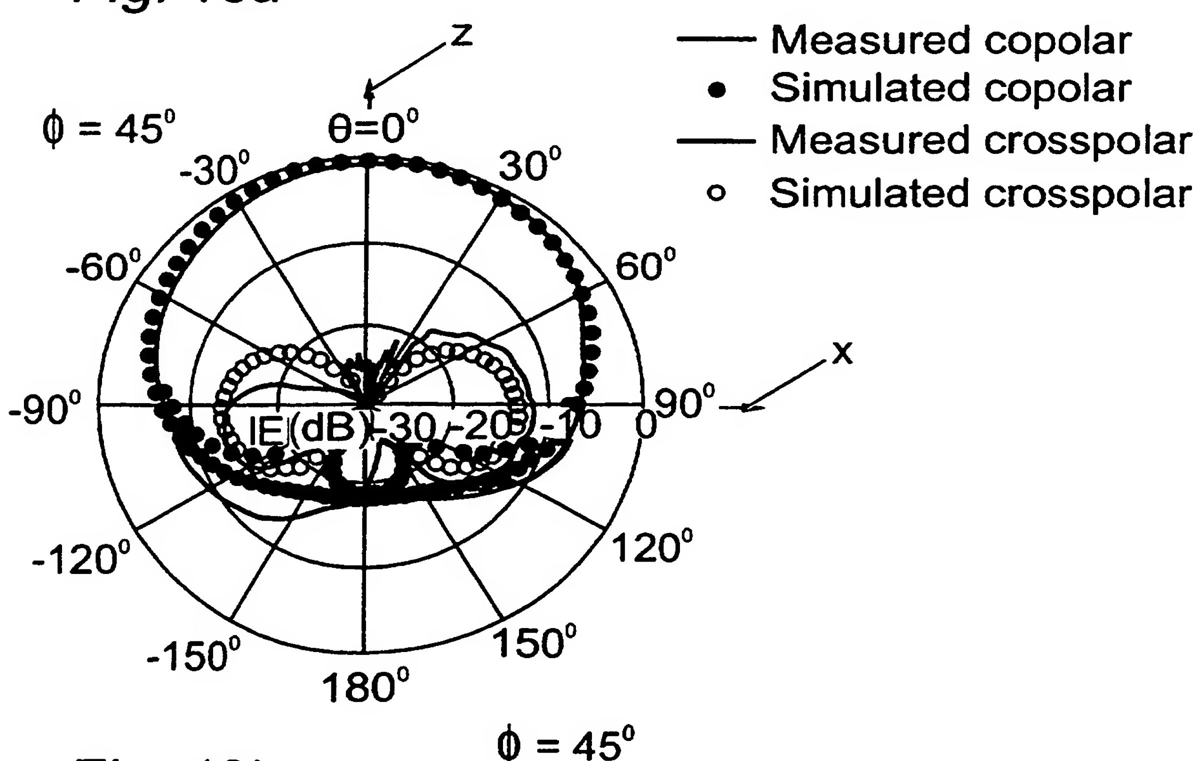


Fig. 13b

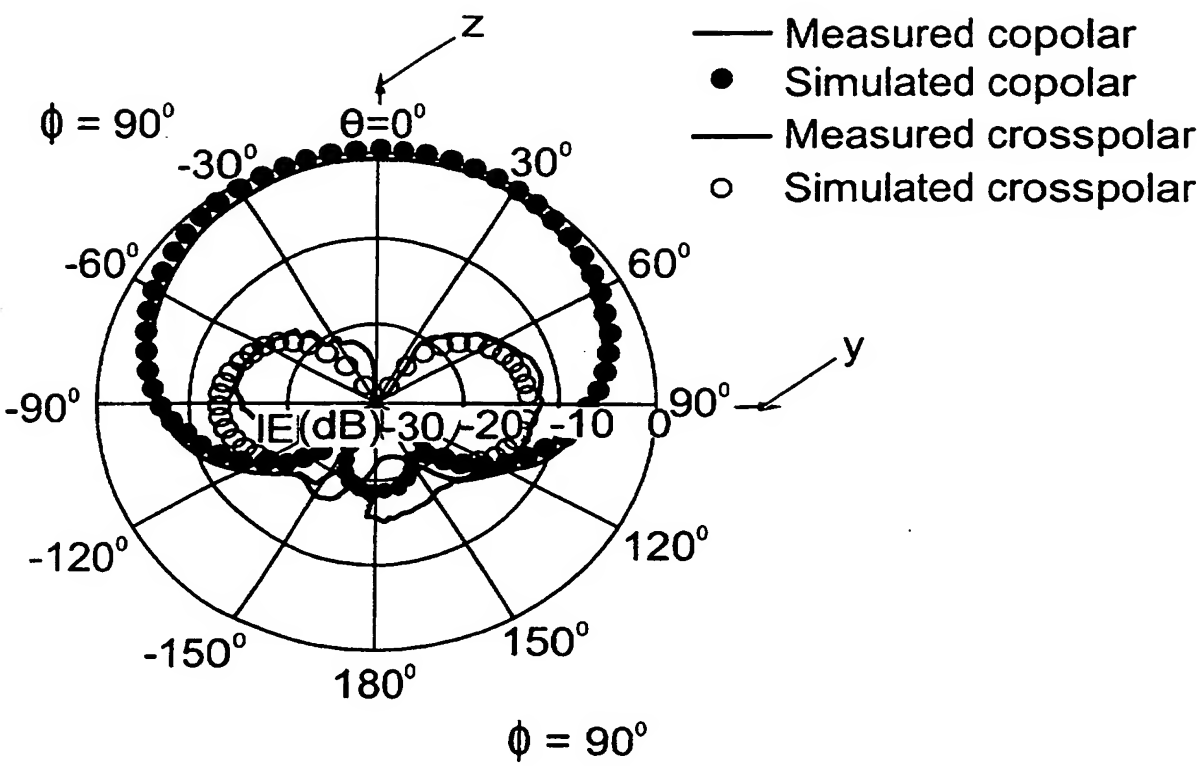

z
y
Measured copolar
Simulated copolar
Measured crosspolar
Simulated crosspolar
ϕ = 90°
θ=0°
-30°
30°
-60°
60°
-90°
90°
-120°
120°
-150°
150°
180°
IE(dB)
-30
-20
-10
0
ϕ = 90°

Fig. 13c

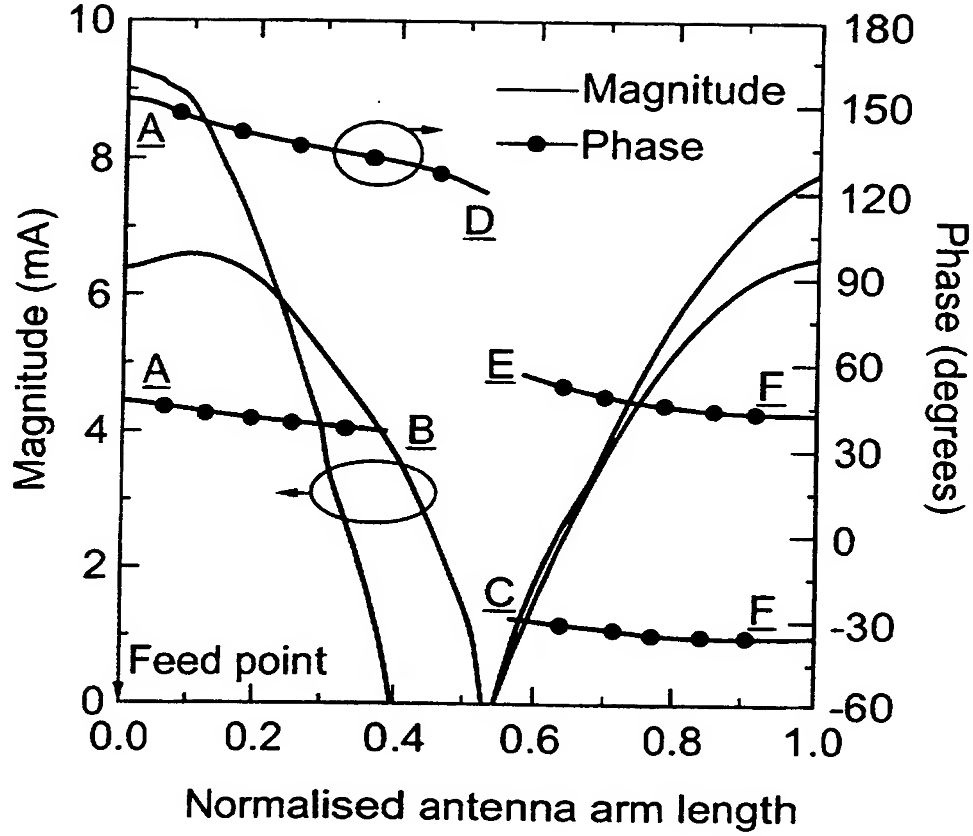

10
8
6
4
2
0
Magnitude (mA)
180
150
120
90
60
30
0
-30
-60
Phase (degrees)
0.0
0.2
0.4
0.6
0.8
1.0
Normalised antenna arm length
Magnitude
Phase
A
D
A
B
E
F
C
F
Feed point

Fig. 14

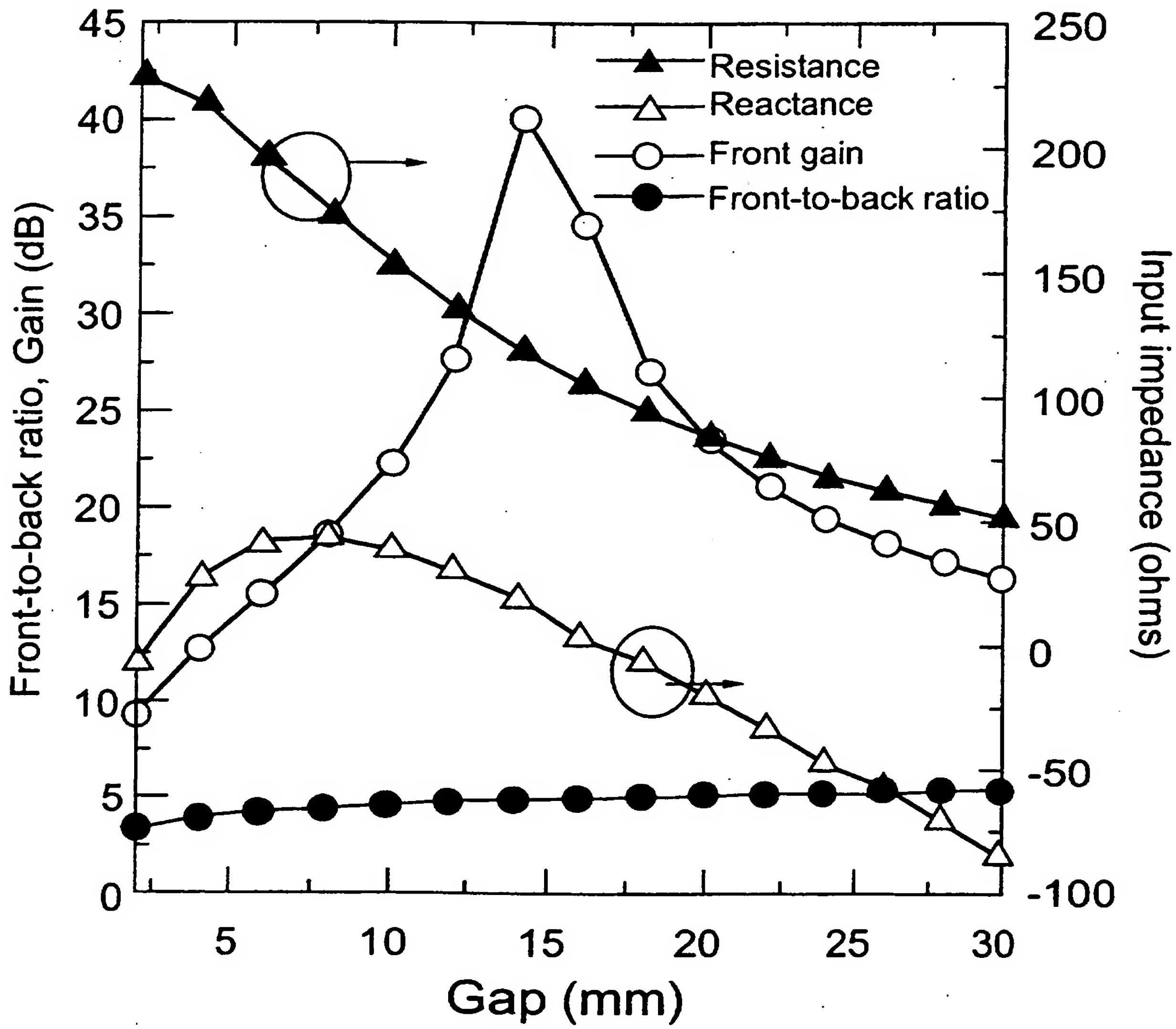

Resistance
Reactance
Front gain
Front-to-back ratio
Front-to-back ratio, Gain (dB)
Input impedance (ohms)
Gap (mm)
45
40
35
30
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30

Fig. 15

2380325

"Improvements relating to Antennas"

This invention relates to antennas, and more particularly to antennas suitable for use in V/UHF bands in mobile applications, and for use in applications such as personal communications and GPS.

For a receiving antenna, the primary requirement is usually large signal-to-noise ratio [1]. Thus a unidirectional radiation pattern with a high front-to-back ratio is desirable to minimise reception of interference from the back direction.

An object of the present invention is to provide antennas which provide a good front-to-back ratio in a manner which is simple and inexpensive to produce.

The present invention, in its widest aspect, provides an antenna comprising a wire loop which is interrupted by two opposed gaps.

Preferably, the wire loop is embedded in a block of dielectric, or is a metallic track on a dielectric substrate, most preferably formed by etching copper on a PCB.

In these forms, the invention can be used to provide a unidirectional loop antenna with a radiation pattern which is linearly polarised with a front-to-back ratio of more than 20 dB.

This may be compared with prior art such as a unidirectional dipole developed by Mikuni et al. for use in the VHF band [2] and a balanced directional loop antenna constructed by Brennan et al. to operate in the V/UHF band [3]. Both antennas were electrically small and resistively loaded, and therefore they had typical gain of around 13 dB below that of a half-wavelength dipole, and also exhibited poor input impedance characteristics.

In another form of the present invention, two antennas as defined above are arranged orthogonally. In this form, the antenna can provide a backfire radiation pattern which is circularly polarised and has a cardioid pattern, again with a front-to-back ratio of more than 20 dB.

The antenna in this form operates similarly to a quadrifilar helix antenna. Since quadrifilar helix antennas were developed by Gerst [4] and Kilgus [5]-[6] several decades ago, they have found a variety of applications in ground station and space

communications, such as GPS receivers [7] and satellite spacecraft [8].

In this form of the invention, the antenna may be fed in a four-feed arrangement via a quadrature circuit; alternatively, by suitable choice of gap widths a one-feed arrangement may be employed.

The antenna of the present invention may be further refined by providing switching means across the loop gaps, whereby the gaps may be selectively open circuit or short circuit. When the gaps are short circuited in the orthogonally crossed arrangement, the radiation pattern is switched to a horizontal linearly polarised pattern. This allows a single antenna to be used for receiving satellite signals (circularly polarised) and terrestrial, e.g. cellphone, signals (linearly polarised).

Embodiments of the invention will now be described, by way of example only, with reference to the drawings, in which:

Fig. 1 illustrates a unidirectional antenna forming a first embodiment of the invention;

Fig. 2 shows predicted frequency response of various parameters for the antenna of Fig. 1;

Figs. 3(a) and 3(b) show measured and predicted radiation patterns at 1 GHz for the antenna of Fig. 1, in the E-plane and H-plane respectively;

Fig. 4 shows the current distribution along the antenna of Fig. 1;

Fig. 5 is a comparison of measured and simulated VSWR for the antenna of Fig. 1 in a 50Ω system;

Fig. 6 illustrates a second embodiment in the form of a four-feed quadrifilar loop antenna;

Fig. 7 shows the frequency responses of various parameters of the antenna of Fig. 6;

Fig. 8(a) shows the radiation pattern at 1 GHz for the antenna of Fig. 6 with $\phi = 0$;

Fig. 8(b) shows the same pattern for $\phi = 45°$;

Fig. 9 shows the current distribution along one arm of the antenna of Fig. 6;

Fig. 10 illustrates a further embodiment in the form of a one-feed quadrifilar loop antenna;

Fig. 11 shows the frequency responses of various parameters of the antenna of Fig. 10;

Fig. 12 shows input impedance characteristics of the antenna of Fig. 10;

Figs. 13(a), 13(b) and 13(c) show the radiation patterns at 1 GHz for the antenna of Fig. 10 at, respectively, $\phi = 0$, $\phi = 45°$, and $\phi = 90°$;

Fig. 14 shows the current distribution along two adjacent arms of the antenna of Fig. 10; and

Fig. 15 shows the effect of varying the size of gaps in the embodiment of Fig. 10.

Referring to Fig. 1, in a first embodiment an antenna comprises a conducting loop 10 which is etched in copper on a PCB. The principal dimensions are given in Fig. 1 in mm. The loop 10 has a width $w = 6$ mm and a thickness $t = 17.5$ μm printed on an

RT/Duroid dielectric substrate (thickness = 0.254mm, $\varepsilon_r = 2.2$).

The antenna is centre-fed by a quarter-wavelength folded balun of conventional design constructed from 50Ω coaxial cable.

The total length of the loop 10 is about one wavelength (λ_0) and the separation between parallel sides AH and DE is $\lambda_0/4$.

It is well known that a one-wavelength loop antenna has a bi-directional figure-of-eight radiation pattern in the H-plane (x-y plane, Fig. 1). In the present invention, this is modified by introducing gaps in opposite sides of the loop.

In the present embodiment, gaps 12 and 14 are provided in the parallel sides AD and HE of the loop 10. The gaps act as capacitances and, by adjusting the gap width BC or GF, back-fire operation with maximum directivity in the positive x-direction can be obtained.

To obtain a maximum front-to-back ratio, a design optimisation was carried out based on a wire grid model numerically simulated using NEC [9]. In the simulation, the etched copper strip 10 of Fig. 1, width w, was modelled by a circular wire with an equivalent wire radius $r = w/4$. Due to the very small substrate thickness and its low dielectric

constant, the impact of the dielectric substrate was considered to be negligible.

At a gap of 14.5 mm the theoretical maximum front-to-back ratio was optimised to be 50 dB. The frequency response of the front-to-back ratio, gain and impedance are shown in Fig. 2. It is observed that the predicted 10-dB front-to-back ratio bandwidth is about 15%. The theoretical maximum power gain is found to vary from 5.6 dBi at 0.9 GHz to 3.4 dBi at 1.1 GHz, and 4.8 dBi at 1 GHz.

The radiation patterns simulated at 1 GHz in the E-plane (x-z plane) and H-plane (x-y plane) are plotted in Fig. 3 together with measured results for comparison. Good agreement is obtained. The small difference between simulation and measurement in the backward direction is probably due to the scattering from the feeding structure. Experimentally we observe a front-to-back ratio of more than 20 dB with maximum gain of 4.5 dBi, and in all cases cross-polarisation levels better than -20 dB.

From Fig. 3 it is also noted that the radiation patterns in both planes exhibit a well formed cardioid. The mechanism of the exhibition of the cardioid pattern can be understood by checking the current distribution along the antenna as seen in Fig. 4. It is seen that the currents on sides AH and DE have the same magnitude but with a 90° phase difference induced by the presence of the capacitive gaps at BC and FG. Note that the current on side DE

is 90° ahead of that on side AH, and that the space separation between the two sides is a quarter wavelength.

For the H-plane pattern, therefore, the antenna can be considered to behave as an array of two dipoles with a separation $\lambda_0/4$ and phase excitation difference 90° . Hence the current phasing and spatial distribution meets the requirement for endfire operation in the positive x-direction. For the E-plane pattern, however, the contributions from sides AD and HE must be taken into account. This is the reason why, in the E-plane. the pattern has a broader beamwidth than that for a typical two-dipole array arranged for endfire.

The input impedance of the loop antenna 10 is plotted in Fig. 2 as a function of frequency. Around 1 GHz the value of the input impedance is about 120+j Ω, which corresponds to a VSWR of 1.6 in a 75-Ω reference. When matched to 75 Ω the system gives VSWR < 2 over the frequency range from 0.9 GHz to 1.1 GHz. The input VSWR measured in a 50-Ω reference system is compared with the simulated result in Fig. 5; here good agreement is observed.

It should be noted that if the gaps BC and FG in Fig. 1 were short-circuited, there would be a continuous loop antenna which will exhibit a bi-directional figure-of-eight radiation pattern in the H-plane. Thus, by providing suitable switching means the antenna of Fig. 1 may be switched from one

form to the other; this can be used for electrical beam switching, which can be exploited for sensor applications such as RF direction sensing.

The embodiment of Fig. 1, in summary, provides an antenna with (a) high front-to-back ratio (> 20 dB), (b) moderate gain (4.5 dBi), and (c) good input impedance characteristics (easily matched to 75-Ω transmission line). The example shown is designed to operate at 1 GHz, has a minimum VSWR of 1.01 at 900 MHz, and exhibits a VSWR of less than 3 over the frequency range 850 MHz to 1090 MHz. Such an antenna can find applications in mobile communications systems where simplified feed arrangements are required.

In a modification (not shown), the antenna of Fig. 1 can be provided in the form of a wire loop, for example a single copper track, embedded in a block of dielectric and having opposed gaps. Effective dimensions equal to Fig. 1 may be used, for example. In this form, the antenna can be provided as a monoblock construction similar to those used by radio part manufacturers for filter parts.

Turning to Fig. 6, there is shown in schematic isometric view a four-feed quadrifilar loop antenna. The antenna comprises a first loop 20 and a second loop 22 having the dimensions shown in mm. Each loop 20, 22 is formed by etching copper strips on an RT/Duroid 5880 dielectric substrate as in the embodiment of Fig. 1. The strip width is 6mm.

Capacitive gaps 24 and 26 are provided as shown in each of the vertical legs to facilitate phasing for production of a cardioid shape.

The antenna of Fig. 6 was numerically simulated using NEC [9]. The calculated front-to-back ratio, directivity gain, and input impedance at each feed point over a range of frequencies are shown in Fig. 7. The maximum front-to-back ratio is about 50 dB at 1 GHz, and the 10-dB front-to-back ratio bandwidth is about 15%. The theoretical directivity in the maximum direction (z-direction) is found to vary from 5.6 dB at 0.9 GHz to 3.4 dB at 1.1 GHz. The input impedance has a resistance of 60 Ω and a reactance of 10 around 1 GHz, which is easy to match to a 50-Ω transmission line.

The simulated and measured radiation patterns in $\phi=0$ and $\phi=45^\circ$ planes are plotted in Fig. 8. The measured front-to-back ratio for the co-polarisation is better than 20 dB. Minimal scattering was observed from the feeding structure, which consists of a quadrature hybrid and two quarter-wavelength folded baluns.

The backfire property of the quadrifilar loop antenna can be understood by viewing the current distribution along each arm of the antenna, Fig. 9. It is seen that the currents on sides AB and FE have the same magnitude and a phase difference of nearly 90°. Note that the current on side FE has a phase lead of 90° with respect to that on side AB, and

that the separation between the two sides is a quarter wavelength. Therefore, sides AB and FE establish the condition necessary for radiation of a cardioid shaped pattern with a maximum in the z-direction. All four arms fed in phase quadrature produce a cardioid shaped, circularly polarised pattern.

The quadrifilar loop antenna can also radiate a cardioid shaped, circularly polarised pattern without using any external circuit such as the hybrid component. The condition to excite the circular polarised waves can be established by a balun and the self-phasing of two orthogonal rectangular wire loops with different gap width.

Referring to Fig. 10, the construction of the antenna itself is similar to that of Fig. 6 except that the gaps 24 in the loop 20 are relatively wide and the gaps 26 in the other loop 22 are relatively smaller.

Two adjacent arms of the quadrifilar loop are connected to one half of the balanced output of the balun, while the other two adjacent arms are connected to the other half of the balun, the connecting points being indicated at 27. The desired 90° phase difference is obtained by selecting the gaps such that the wider gaps 24 are capacitive, while the smaller gaps 26 are inductive. This technique is similar to that applied in a

single-fed crossed-dipole antenna for circular polarisation [10].

The calculated front-to-back ratio and gain are shown in Fig. 11 which indicates approximately a 10-dB front-to-back ratio bandwidth of 12% and an average gain of 5dB over the bandwidth. The frequency dependence of axial ratio is also presented in Fig. 11. The measured maximum axial ratio was found to be about 0.7 dB and the axial ratio bandwidth of less than 3 dB is approximately 10%.

Fig. 11 also shows the input impedance characteristics. It can be seen that the input VSWR is less than 2 over the 3-dB axial ratio and over the 10-dB front-to-back ratio bandwidth. The measured and calculated radiation patterns at 1GHz are plotted in Fig. 12, which shows better than 18 dB front-to-back ratio and a half-power beamwidth of approximately 120°.

The current distribution along two adjacent arms of the one-feed quadrifilar loop antenna is shown in Fig. 14. It is observed that the phase difference between adjacent arms, say AD and AB, is indeed about 90° which is the necessary condition to produce circular polarisation. In addition, we note that the phase difference between the upper and lower sides (e.g. AB and CF) of each arm appears in order of 90°, an important condition for a cardioid shaped pattern.

Fig. 15 shows the effect of varying the smaller gaps, while maintaining the wider gaps at 31 mm.

Thus, the embodiments of Figs. 6 and 10 provide new quadrifilar antennas having similar properties to quadrifilar helix antennas in producing circularly polarised backfire patterns, but with structures which are much easier to produce.

Both Fig. 6 and Fig. 10 can be modified by providing switching means, such as transistors, selectively operable to short circuit the gaps, as shown schematically at 28 in Fig. 10. When the gaps are open circuit, they antenna behaves as described above. When the switching means are operated to short circuit the gaps, the antenna has a radiation pattern which is omnidirectional and linearly polarised in the x-y plane.

Modifications and improvements may be made to the foregoing embodiments within the scope of the present invention.

References

[1] Kraus, J D: 'Antennas - Second Edition', McGraw-Hill, Inc, 1988, pp 766-767.

[2] Mikuni, Y and Nagai, K: 'Unidirectional dipole antenna', Electronics Letters, Sept. 1972, 19(8), pp 472-473.

[3] Brennan, P V and Valverde, Y: 'Balanced directional loop receiving antenna', Electronics Letters, Sept. 1991, 15(27), pp 1320-1321.

[4] Gerst, C and Worden, R A: 'Helix antennas take turn for better', Electronics, Aug. 1996, pp 100-110.

[5] Kilgus, C C: 'Multi-element fractional turn helices', IEEE Trans Antennas Propagat, 1968, AP-16, pp 499-500.

[6] Kilgus, C C: 'Resonant quadrifilar helix', IEEE Trans Antennas Propagat, 1969, AP-17, pp 349-351.

[7] Tranquilla, J M and Best, S R: 'A study of the quadrifilar helix antenna for global positioning system (GPS) applications', IEEE Trans Antennas Propagat, 1990, AP-38, pp 1545-1549.

[8] Cahill, R, Cartnell, I, Dooren, G, Clibbon, K and Sillence, C: 'Performance of shaped beam quadrifilar antennas on the METOP spacecraft', IEE Proc - Microw Antennas Propag, 1998, 1(145), pp 19-24.

[9] NEC-Win Professional V1.1a, © 1997, Nittany Scientific Inc, USA.

[10] Maamria, K and Nakamura, T: 'Simple antenna for circular polarisation', IEE Proc - Microw Antennas Propag, 1992, 2(139), pp 157-158.

CLAIMS

1. An antenna comprising a wire loop which is interrupted by two opposed gaps.

2. An antenna according to claim 1, in which the wire loop is embedded within a block of dielectric.

3. An antenna according to claim 1, in which the wire loop is a metallic track on a dielectric substrate.

4. An antenna according to claim 3, in which the metallic track is formed by etching copper on a PCB.

5. An antenna according to claim 3 or claim 4, which forms a unidirectional loop antenna with a radiation pattern which is linearly polarised with a front-to-back ratio of more than 20 dB.

6. An antenna comprising two antennas as claimed in any preceding claim arranged orthogonally.

7. An antenna according to claim 6, which provides a backfire radiation pattern which is circularly polarised and has a cardioid pattern, with a front-to-back ratio of more than 20 dB.

8. An antenna according to claim 6 or claim 7, the antenna being fed in a four-feed arrangement via a quadrature circuit,

9. An antenna according to claim 6 or claim 7, the antenna having a one-feed arrangement and gap widths dimensioned such that the gaps in one loop are capacitive and the gaps in the other loop are inductive.

10. An antenna according to any preceding claim, including switching means connected across at least one of the loop gaps, whereby the gap or gaps may be selectively open circuit or short circuit.

11. An antenna according to any of claims 6 to 9, including switching means connected across the loop gaps, the switching means being selectively operable to short circuit the gaps to provide a horizontal linearly polarised radiation pattern, and to open circuit the gaps to provide a circularly polarised radiation pattern.

The Patent Office

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Application No: GB 0211460.1 \6
Claims searched: 1 to 11

Examiner: Peter Easterfield
Date of search: 23 January 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1,3,4	EP 0829917 A1	(MITSUBISHI)
X	1	GB 1272990 A	(SONY)
X	1	DE 4327917 A	(MEISSNER)
X	1	US 4620155 A	(EDELSTEIN)
X	1	US 3761933 A	(SMALSER)
X	1	WO 97/01197 A1	(MOTOROLA)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

H1Q

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

H01Q

The following online and other databases have been used in the preparation of this search report:

WPI, EPODOC, JAPIO